| | L # | Hits | Search Text | DBs | Time Stamp |
|---|---|---|---|---|---|
| 1 | L3 | 19 | (("6337289") or ("20020009861") or ("5046045") or ("5392189") or ("5959702") or ("6001702") or ("2004026621") or ("6797525")).PN. | US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 18:10 |
| 2 | L5 | 8 | 3 and (aluminum or Al or AlO or "Aluminum oxide" or AlON or "Aluminum oxynitride" or AlN or "Aluminum nitride") | US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 19:21 |
| 3 | L6 | 6 | 5 and (temp or degree or temperature) | US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 18:29 |
| 4 | L7 | 4 | (("5959327") or ("5046045")).PN. | US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 18:32 |

| | L # | Hits | Search Text | DBs | Time Stamp |
|---|---|---|---|---|---|
| 5 | L8 | 2 | ("5046045").PN. | US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 18:32 |
| 6 | L9 | 2 | 7 and (aluminum or Al or AlO or "Aluminum oxide" or AlON or "Aluminum oxynitride" or AlN or "Aluminum nitride") | US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 18:34 |
| 7 | L10 | 853 | expos$6 near4 (Al or Aluminum) near8 (oxygen or nitrogen or N or O) | US-PGPUB; USPAT; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 19:20 |
| 8 | L11 | 624 | L10 and temperature | US-PGPUB; USPAT; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 19:20 |

| | L # | Hits | Search Text | DBs | Time Stamp |
|---|---|---|---|---|---|
| 9 | L12 | 435 | L11 and ((@ad<"20010105") or (@rlad<"20010105")) | US-PGPUB; USPAT; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 19:20 |
| 10 | L13 | 156 | L12 and (low near2 temperature) | US-PGPUB; USPAT; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 19:20 |
| 11 | L14 | 156 | 13 and (aluminum or Al or AlO or "Aluminum oxide" or AlON or "Aluminum oxynitride" or AlN or "Aluminum nitride") | US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 19:21 |
| 12 | L15 | 25 | 14 and capacitor | US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB | 2005/06/07 19:21 |

US-PAT-NO: 6245606

DOCUMENT-IDENTIFIER: US 6245606 B1

TITLE: **Low temperature** method for forming a thin, uniform layer of **aluminum oxide**

---------- KWIC ---------

Abstract Text - ABTX (1):
This invention pertains generally to forming thin **aluminum oxides at low temperatures,** and more particularly to forming uniformly thick, **aluminum** gate oxides. We disclose a **low temperature** method for forming a thin, uniform **aluminum** gate oxide 16 on a silicon surface 12. This method includes providing a partially completed integrated circuit on a semiconductor substrate 10 with a clean, hydrogen terminated or atomically flat, silicon surface 12; forming a uniformly thick **aluminum** layer 13; and stabilizing the substrate at a first **temperature**. The method further includes exposing the **aluminum** layer to an atmosphere 14 including ozone, while maintaining the substrate 10 at the first **temperature**. In this method, the exposing step creates a uniformly thick, **aluminum oxide** film 16. This method is suitable for room **temperature** processing.

Application Filing Date - AD (1):
**19991020**

TITLE - TI (1):
**Low temperature** method for forming a thin, uniform layer of **aluminum oxide**

Brief Summary Text - BSTX (2):
This invention pertains generally to forming **aluminum oxide** dielectrics at **low temperatures,** and more particularly to forming **aluminum** gate oxide layers with high thickness uniformity.

Brief Summary Text - BSTX (7):

Pure SiO.sub.2 gate dielectrics will not be scaleable below 2 nm because of reliability problems (premature breakdown) and high leakage. This lack of scaleability motivates the search for higher dielectric constant materials. Generally, the search has centered on materials with .epsilon.>20-50, thus providing significant margin. However, we believe that even moderate dielectric constant materials (.epsilon.=10) can provide useful gate dielectrics, if a suitable manufacturing method is developed. Al.sub.2 O.sub.3 's thermodynamic stability on Si and moderate dielectric constant (.epsilon.=10) makes it a potential choice for a gate dielectric. We believe this usefulness may exist even though many artisans have avoided **aluminum** contact with Si, due to the potential of spiking.

Brief Summary Text - BSTX (8):

The current method typically used for forming Al.sub.2 O.sub.3 is sputtering pure **Al** in an AR/O.sub.2 ambient. This sputter deposition method of **Al** in an O.sub.2 ambient tends to oxidize the Si substrate at onset of deposition, forming an undesirable SiO.sub.2 layer. It is also difficult to reproducibly deposit .about.30-60 angstroms this way.

Brief Summary Text - BSTX (9):

Sputter deposition, rapid thermal oxidation and furnace annealing are three current methods for forming **aluminum oxide** gate dielectrics. However, current methods do not reliably produce gate oxides with the thickness uniformity and interface smoothness that will be needed to make devices with approximately 2-4 nm gate oxides practical. Additionally, these methods add significantly to the wafer's thermal budget.

Brief Summary Text - BSTX (10):

We disclose a **low temperature** method for forming a thin **aluminum oxide** gate dielectric on a silicon surface, the method includes providing a partially completed integrated circuit on a semiconductor substrate with a

clean silicon
surface; determining a first planned **temperature**--no greater than about 300
degrees C.--for an **aluminum oxide** film formation; thereby substantially
determining a potential thickness of oxidizable **aluminum**. The method further
includes forming a uniformly thick layer of **aluminum** on the silicon surface to
form a temporary **aluminum** layer, the temporary **aluminum** layer having a
thickness no greater than the potential thickness of oxidizable **aluminum**;
stabilizing the substrate at the first planned **temperature**; and exposing the
temporary **aluminum** layer to an atmosphere including ozone, while maintaining
the substrate at the first planned **temperature**. In this method, the exposing
step creates a first, uniformly thick, **aluminum** gate oxide film. The method
also typically includes forming a gate electrode on the **aluminum** gate oxide
film.

Brief Summary Text - BSTX (11):
In some embodiments, exposing the **aluminum** layer to an atmosphere including
ozone uses a commercial ozone generator, while others include **exposing the**
**aluminum layer to an atmosphere including molecular oxygen,** while irradiating
at least a portion of the atmosphere with an ultraviolet light, where the light
transforms some of the oxygen to ozone. In some embodiments, the atmosphere
further includes an inert gas, such as argon. Preferably, the ozone at the
**aluminum** layer is not in an excited energy state, such as a plasma. However, a
plasma kept away from the wafer may be acceptable.

Brief Summary Text - BSTX (13):
In some embodiments, the first planned **temperature** is about 25 degrees C.
and the **aluminum** gate oxide film has a thickness of about 10 angstroms. In
other embodiments, the first **temperature** may be up to about 300 degrees C., or
even up to 530 degrees C. These **temperatures** will grow thicker oxides

(up to about 50 angstroms) as shown in FIG. 3.

Brief Summary Text - BSTX (14):

In another aspect of this method, the method further includes depositing a uniformly thick layer of **aluminum** on the first **aluminum oxide** film to form a temporary **aluminum** layer, the temporary **aluminum** layer having a thickness no greater than the potential thickness of oxidizable **aluminum**. This potential thickness is found by determining a second planned substrate **temperature** for a second oxide film formation, the planned **temperature** no greater than about 300 degrees C.--often the same as the first planned **temperature**. This planned **temperature** substantially determines the potential thickness of oxidizable **aluminum**. After depositing the **aluminum**, the method further includes exposing the temporary **aluminum** layer to a second atmosphere containing ozone, while the substrate is at the planned substrate **temperature**. This exposing step oxidizes the temporary **aluminum** layer to form a second, uniformly thick, **aluminum oxide** film extending to the first oxide film; thereby creating a single (combined), uniformly thick, **aluminum oxide** film.

Brief Summary Text - BSTX (15):

In some embodiments, the method further includes stabilizing the substrate at the second planned substrate **temperature** before the exposing step.

Drawing Description Text - DRTX (2):

FIGS. 1A-1C show a **low temperature** method for forming a very thin, uniform **aluminum oxide** layer.

Drawing Description Text - DRTX (3):

FIGS. 2A-2D show a **low temperature** method for forming a very thin, uniform **aluminum oxide** layer.

Drawing Description Text - DRTX (4):

FIG. 3 shows a relationship between time, **aluminum oxide** thickness, and

oxides with
this method. We have found that, if the thermal budget allows, we can easily
produce high quality, 4-5 nm thermal oxides at only 500.degree. C. Sometimes
an artisan may prefer to use lower **temperatures,** but grow substantially thicker
layers than shown in FIG. 3. For this case, we add extra steps as shown in
FIG. 2, but still obtain a highly uniform oxide.

Detailed Description Text - DETX (14):
This variation involves first forming a highly uniform **aluminum oxide** layer
16 on a silicon surface 12 as described above. Next, another **aluminum** layer 18
is deposited on the **aluminum oxide** layer 16. The thickness and uniformity of
the final oxide layer will depend upon the thickness of the **aluminum** layer 18.
Thus, like above, **aluminum** layer 18 should be formed with a well-controlled
method, such as sputter deposition or atomic layer epitaxy. This new **aluminum**
**surface is then exposed to another ozone/oxygen** atmosphere 14, forming a single
Al.sub.2 O.sub.3 layer 20. In this step, the total thickness of **aluminum oxide**
layer 20 is determined by the thickness of the **aluminum** 18 and the underlying
**aluminum oxide** layer 16. However, the ozone allows complete oxidation of much
thicker **aluminum** layers than a straight oxygen atmosphere. If necessary, this
**aluminum** deposition and oxidation can be repeated to form thicker layers.

Detailed Description Text - DETX (15):
FIG. 4 shows a metal-oxide-silicon field-effect transistor (MOSFET)
embodiment of this invention. Field-effect transistor 22 has four principal
parts: a substrate 24, a source 26, a drain 28, and a gate, where the gate
includes the gate electrode 30 and thin **aluminum oxide** gate dielectric 32. For
an NMOS transistor 22, p-type silicon substrate 24 includes n+ source 26 and
n+drain 28 regions. Gate dielectric 32 is a very thin, very uniform, **aluminum**

**oxide** film, formed by using ozone to oxidize an **aluminum** layer on clean silicon substrate 24. MOSFET transistor 22 also includes sidewall spacers 34, lightly doped drain (LDD) region 36, and isolation region 38. Those skilled in the art will recognize that these and other features may be used or left out, depending upon the particular function of the device and the intended processing flow.

Detailed Description Text - DETX (16):

These examples have shown NMOS transistors. Since the ozone-based thin **aluminum** gate oxide method is substantially insensitive to the doping profile of Si, no special modifications are required to implement this invention in PMOS devices or CMOS devices; or into Al.sub.2 O.sub.3 based **capacitors,** which require a thin, very uniform dielectric with low electrical leakage and a high breakdown voltage.

Detailed Description Text - DETX (17):

Although this method provides substantial benefits when used to form thin oxide layers, it can also offer an improvement over typical methods for forming thicker high-quality oxide layers, such as a dielectric around the floating gate in a flash memory cell. If the thermal budget permits, this ozone-based method can be used to form relatively thick Al.sub.2 O.sub.3 layers in a single pass, or even thicker layers in a layered approach like that described above. Although these thicker layers may require **temperatures** above 500 degrees C., this variation of the ozone-based method allows lower **temperature** processing than conventional oxidation processes. Not only do these lower **temperatures** help the thermal budget, but the self-limiting nature of a ozone-based process improves process repeatability and oxide thickness uniformity, without sacrificing the oxide's electrical quality.

Claims Text - CLTX (1):

1. A **low temperature** method for forming a thin gate dielectric on a silicon
surface, the method comprising:

Claims Text - CLTX (3):
providing a first **temperature for an aluminum oxide** film formation, the
first **temperature** no greater than about 300 degrees C.; thereby substantially
determining a potential thickness of oxidizable **aluminum**;

Claims Text - CLTX (4):
forming a uniformly thick layer of **aluminum** on the silicon surface to form a
temporary **aluminum** layer, the temporary **aluminum** layer having a thickness no
greater than the potential thickness of oxidizable **aluminum**.

Claims Text - CLTX (5):
stabilizing the substrate at the first **temperature**;

Claims Text - CLTX (6):
exposing the temporary **aluminum** layer to an atmosphere including ozone,
while maintaining the substrate at the first **temperature,** wherein the exposing
step creates a first, uniformly thick, **aluminum** gate oxide film.

Claims Text - CLTX (7):
2. The method of claim 1, wherein exposing the **aluminum** layer to an
atmosphere including ozone comprises:

Claims Text - CLTX (8):
**exposing the aluminum layer to an atmosphere including molecular oxygen,**
while irradiating at least a portion of the atmosphere with an ultraviolet
light, the light operative to transform some of the oxygen to ozone.

Claims Text - CLTX (10):
4. The method of claim 1, wherein exposing the **aluminum** layer to an
atmosphere including ozone includes exposing the **aluminum** layer to an
atmosphere with less energy than a plasma.

Claims Text - CLTX (11):
5. The method of claim 4, wherein at least part of the atmosphere that does
not contact the **aluminum** layer includes an ozone plasma.

Claims Text - CLTX (13):
7. The method of claim 1, further comprising forming a gate electrode on the **aluminum** gate oxide film.

Claims Text - CLTX (14):
8. The method claim 1, wherein the fist **temperature** is about 25 degrees C. and the **aluminum** gate oxide film has a thickness of about 10 angstroms.

Claims Text - CLTX (15):
9. The method of claim 1, wherein the first **temperature** is between 0 and 300 degrees C. and the **aluminum** gate oxide film has a thickness between 5 and 30 angstroms.

Claims Text - CLTX (16):
10. The method of claim 1, wherein the first **temperature** is about 300 degrees C.

Claims Text - CLTX (17):
11. The method of claim 1, wherein the first **temperature** is about 300 degrees C. and the **aluminum** gate oxide film has a thickness of about 30 angstroms.

Claims Text - CLTX (19):
providing a second **temperature** for a second **aluminum oxide** film formation, the second **temperature** no greater than about 300 degrees C.; thereby substantially determining a second potential thickness of oxidizable **aluminum**;

Claims Text - CLTX (20):
depositing a uniformly thick layer of **aluminum** on the first **aluminum** gate oxide film to form a second temporary **aluminum** layer, the second temporary **aluminum** layer having a thickness no greater than the second potential thickness of oxidizable **aluminum**;

Claims Text - CLTX (21):
exposing the second temporary **aluminum** layer to a second atmosphere

including ozone, while the substrate is at the second **temperature,**

Claims Text - CLTX (22):
wherein the exposing step oxidizes the second temporary **aluminum** layer to
form a second, uniformly thick, oxide film extending to the first oxide film;
thereby creating a combined, uniformly thick, **aluminum** gate oxide film.

Claims Text - CLTX (24):
stabilizing the substrate at the second **temperature** before the exposing
step.

Claims Text - CLTX (26):
repeating the depositing, and exposing to an atmosphere including ozone
steps at least once; thereby increasing the thickness of the combined **aluminum**
gate oxide film.

Claims Text - CLTX (27):
15. The method of claim 12, wherein the first **temperature** and the second
**temperatures** are about 25 degrees C. and the combined **aluminum** gate oxide film
has a thickness of about 40 angstroms.

Claims Text - CLTX (28):
16. A **low temperature** method for forming a thin **aluminum** gate oxide on a
silicon surface, the method comprising:

Claims Text - CLTX (30):
providing a first **temperature for an aluminum oxide** film formation, the
first **temperature** no greater than about 300 degrees C.; thereby substantially
determining a potential thickness of oxidizable **aluminum**;

Claims Text - CLTX (31):
forming a uniformly thick layer of **aluminum** on the silicon surface to form a
temporary **aluminum** layer, the temporary **aluminum** layer having a thickness no
greater than the potential thickness of oxidizable **aluminum**;

Claims Text - CLTX (32):
stabilizing the substrate at the first **temperature**;

Claims Text - CLTX (33):
exposing the temporary **aluminum** layer to an atmosphere including ozone,
while maintaining the substrate at the first **temperature,** wherein the exposing
step creates a first, uniformly thick, **aluminum** gate oxide film; and

Claims Text - CLTX (37):
providing a second **temperature** for a second oxide film formation, the second
**temperature** no greater than about 300 degrees C.; thereby substantially
determining a potential thickness of oxidizable silicon;

Claims Text - CLTX (39):
exposing the temporary silicon layer to a second atmosphere including ozone,
while the substrate is at the second **temperature,**

Claims Text - CLTX (42):
stabilizing the substrate at the second **temperature** before the exposing
step.

US Reference Patentee Name - URNM (1):
Norris et **al.**

US Reference Patentee Name - URNM (2):
Gossler et **al.**

US Reference Patentee Name - URNM (4):
Mishra et **al.**

US Reference Group - URGP (1):
3766637 19731000 Norris et **al.** 438/216

US Reference Group - URGP (2):
4566173 19860100 Gossler et **al.** 438/216

US Reference Group - URGP (4):
5872031 19990200 Mishra et **al.** 438/216